Short-Range Dispersal and Overwintering Habitats of Boll Weevils (Coleoptera: Curculionidae) During and After Harvest in the Subtropics

ALLAN T. SHOWLER[1]

USDA–ARS–APMRU, 2413 East Highway 83, Weslaco, TX 78596

J. Econ. Entomol. 99(4): 1152–1160 (2006)

ABSTRACT Field experiments in the subtropical Lower Rio Grande Valley of Texas were conducted to determine the extent of adult boll weevil, *Anthonomus grandis grandis* Boheman (Coleoptera: Curculionidae), dispersal from cotton, *Gossypium hirsutum* L., fields during harvest operations and the noncotton-growing ("overwinter") period between 1 September and 1 February. Using unbaited large capacity boll weevil traps placed at intervals extending outward from commercial field edges, boll weevils did not move in substantial numbers during harvest much beyond 30 m, primarily in the direction of prevailing winds. From traps placed in fallow cotton; citrus; lake edge; pasture; treeline; sorghum, *Sorghum bicolor* (L.) Moench, and sugarcane, *Saccharum* spp., habitats during the overwinter period, the most boll weevils were collected in the fallow cotton fields and adjacent treelines during the fall. However, the greatest abundances of boll weevils were found in citrus orchards in the spring, before newly planted cotton fields began to square. One of the three lake edges also harbored substantial populations in the spring. Egg development in females was not detected between November and April, but in cotton fields most females were gravid between May and August when cotton fruiting bodies were available. Mated females, as determined by discoloration of the spermatheca, made up 80–100% of the female population during November and December but declined to ≈50% in February. The lower incidence of mating indicates a reduction in physical activity, regardless of overwinter habitat, until percentages increased in March and April after cotton fields had been planted and squares were forming.

KEY WORDS *Anthonomus grandis grandis*, dispersal, food, habitats, overwinter

During the cotton-growing season, boll weevil, *Anthonomus grandis grandis* Boheman (Coleoptera: Curculionidae), populations build up in cotton, *Gossypium hirsutum* L., fields (Showler and Robinson 2005, Showler et al. 2005), particularly when squares become large (5.5–8 mm in diameter) (Showler 2005) and females increase fecundity and gravidity (Showler 2004). When cotton plants are fruiting, however, boll weevils occur in substantially lower numbers in grandlure-baited traps than during harvest-related activities, such as defoliation, harvest, shredding, and stalk-pulling or tillage, which disrupt the pest's preferred habitat and remove the food source (Parajulee and Slosser 2001, Showler 2003). In temperate areas, where boll weevils enter a state of diapause because of low temperatures and possibly lack of food resources (Brazzel and Newsom 1959, Rummel and Summy 1997), several overwintering habitats have been identified, including deciduous leaf litter, pine straw, other ground cover, and various grasses (Bondy and Rainwater 1942, Beckham 1957, Cowan et al. 1963, Bottrell et al. 1972, Brown and Phillips 1989, Carroll et al. 1993).

In the Mesoamerican tropics and subtropics where the boll weevil originated (Burke et al. 1986), the insect is active year-round (Guerra et al. 1982, 1984) because there are alternative sources of food that can sustain boll weevils in the absence of cotton (Cross et al. 1975, Benedict et al. 1991, Jones et al. 1992, Hardee et al. 1999), possibly including the flesh of prickly pear, *Opuntia* sp., cactus and orange, *Citrus sinensis* (L.) Osbeck fruits, for as long as 181 and 246 d, respectively, in the laboratory (A.T.S., unpublished data). Studies on the survival and dispersal of the boll weevil in the subtropics have produced different results. Using boll weevils marked with a colored glue on the elytra, Guerra (1986) suggested that boll-fed weevils dispersed away from cotton fields, and even across the border of the United States and Mexico from cotton fields in the Lower Rio Grande Valley of Texas, as far as 272 km (Guerra 1988). Jones et al. (1992) reported that boll weevils were trapped with ingested pollen grains from plant species whose range was purported

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

[1] Corresponding author, e-mail: ashowler@weslaco.ars.usda.gov.

to be 40 km from the trap location. Johnson et al. (1975) marked boll weevil adults in Mississippi and found them as far as 52 km from the release sites. However, using rubidium-labeled adult boll weevils, Wolfenbarger et al. (1982) reported that the weevils do not move far (≤90 m) from the field of origin, and large numbers of boll weevils were trapped from cotton fields after the growing cotton crop had been removed after harvest (Showler 2003). Beerwinkle et al. (1996) found that boll weevils in central Texas were trapped in the greatest numbers in cropped areas compared with noncropped areas, and a study in South Carolina determined that 90% of boll weevils moved ≤55 m into woodlands after harvest, but most of those were found within 9–14 m into the woods (Fye et al. 1959).

Although grandlure-based trap captures were often used to collect boll weevils in previous dispersal studies (Johnson et al. 1975; Pieters and Urban 1977; Wade and Rummel 1978; Wolfenbarger et al. 1982; Guerra 1986, 1988), the length of the attractive volatile pheromone plume can potentially attract boll weevils from areas away from the trap, thus influencing the results. The purposes of this study were to assess the short-range dispersal of boll weevils from cotton fields during and after harvest without reliance on pheromone lures, to find habitats where substantial populations persist during the noncotton-growing season, and to examine the influence of selected overwintering habitats on mating and fecundity in the absence of squaring cotton.

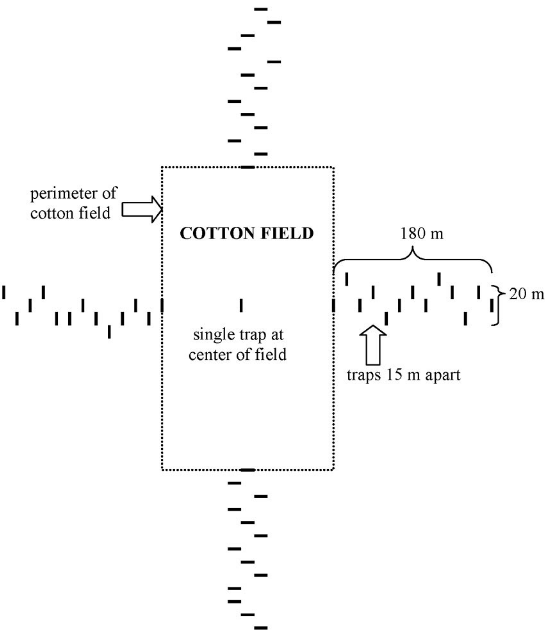

Fig. 1. Illustrative (not drawn to scale) diagram of trap deployment in the short-range dispersal experiment. The sticky traps were not accoutered with grandlure pheromone. In addition to the trap in the middle of each field, the traps outside the fields were located 15 m apart, extending 180 m in each direction.

Materials and Methods

This study was conducted in Hidalgo County, in the Lower Rio Grande Valley of Texas, 2003–2005.

Short-Range Dispersal. Three rectangular commercial cotton (*G. hirsutum*) fields, 10.5–16 ha each (variety not determined), were used for this experiment during 2004. Each side of each field corresponded to a compass direction such that 13 large capacity boll weevil traps (Showler 2003) were deployed, starting at the field edge, 15 m apart extending to 180 m in each compass direction, north, south, east, and west, from a field edge through pastureland or fallow sugarcane, *Saccharum* spp., land. The traps extending from each field edge were placed at random within a 20-m-wide "corridor" such that the traps were not arranged in a straight line (Fig. 1). A single trap was placed at the center of each field; hence, boll weevils were passively collected on the sticky surfaces of the traps. None of the traps were baited with grandlure (Tumlinson et al. 1969). Total numbers of boll weevils per trap were collected over 10 consecutive days before tractor application of *S,S,S*-tributylphosphorotrithioate defoliant on 19, 21, or 25 July to the respective cotton fields. Total numbers of boll weevils per trap also were collected over 10 consecutive days, beginning 4 d after defoliant application when the cotton fields were showing clear signs of foliar desiccation, and including harvest and stalk-pulling 2 and 4 d later, respectively. Defoliation, harvest, and stalk-pulling are all known to disturb adult boll weevils (Showler 2003). Wind direction and speed and ambient minimum and maximum daily air temperatures were recorded at a weather station located within 5 km of all three fields. This part of the study was conducted during 1 yr because, during the next year (2005), the boll weevil eradication program (Dickerson et al. 2001) began, involving mandatory late season applications of malathion that would have disrupted the experiment (Showler and Robinson 2005).

Winter Habitats. There were six locations, or replications, for each of seven different habitat types: fallow cotton; sorghum, *Sorghum bicolor* (L.) Moench; or sugarcane fields, citrus orchards, lake edges (each lake was ≥5 ha), pastures, and treelines along fallow cotton fields. Two large-capacity boll weevil traps (Showler 2003) were positioned 31 m apart within each of 42 habitat locations. Boll weevil numbers were counted every 2 d on large capacity boll weevil traps (Showler 2003), each baited with a 10-mg grandlure strip (replaced every 2 d) in the fall and spring during the noncotton-growing period in Hidalgo County. Fall populations were assessed 18–29 and 16–27 September 2003 and 2004, respectively, and spring populations were assessed 17–28 and 18–29 February 2004 and 2005, respectively. Treelines were principally comprised of mesquite, *Prosopis glandulosa* Torr.; huisache, *Acacia farnesiana* (L.) Willd.; retama, *Parkinsonia aculeata* L.; and hackberry, *Celtis occidentalis* L. Two traps were placed at randomly selected locations along the edges of Donna, Delta, and La Feria lakes (total locations along lake edges, six). The predominant vegetation at Delta Lake was Texas signalgrass, *Urochloa texana* (Buckl.) R. Webster; buffelgrass, *Pennisetum ciliare* (L.) Link; and bamboo (*Bambusa* sp.), but Bermuda grass, *Cynodon dactylon* (L.) Pers., was most common at La Feria and Donna lakes.

Mating Status and Gravidity. One Hercon scout trap (Hercon Environmental, Emigsville, PA) with a 10-mg grandlure strip was deployed in each of five cotton fields, citrus orchards, and treelines and at five locations along the edge of Delta Lake, all located in Hidalgo County. Twenty live female weevils were collected on 5 November, 22 January, 12 February, 17 March, 15 April, 18 May, and 3 November 2004 and on 21 January, 10 February, 15 March, 13 April, and 17 May 2005 from the fallow cotton, treeline, citrus, and Delta Lake habitats while cotton in the area was not squaring. Once cotton began to produce squares, 20 adult female boll weevils were collected from each of the five cotton fields using a beat bucket (Knutson and Wilson 1999, Knutson et al. 2000) on 22 June and 15 July 2004 and on 22 June and 14 July 2005. Twenty weevils from each habitat were dissected for counting developing and chorionated eggs, and for discoloration of the spermatheca, a sign that mating has occurred.

Statistical Analyses. Significant differences were detected using one-way analysis of variance (ANOVA), mean separations were conducted using Tukey's honestly significant difference (HSD) (Analytical Software 1998) for before and after cotton defoliation trap collections, trap collections between habitats, between lakes, and collections during fall versus spring within each habitat. In the winter habitats experiment, captures from the two traps at each location were averaged before ANOVA. For the comparison between the three lakes, all of the traps were considered to be replicates (so each lake had four replicate traps). Percentages were arcsine-square-root-transformed, but nontransformed data are presented (Analytical Software 1998). The short-range dispersal and the fecundity and spermatheca discoloration data were analyzed using repeated measures ANOVA and Tukey's HSD for separating the means (Analytical Software 1998).

Results

Short-Range Dispersal. Differences in weevil numbers were detected between trap locations relative to each cotton field before and after harvest operations began ($F = 3.32$; df = 9, 27; $P = 0.0122$). Mean sums of boll weevils collected in traps extending north of the cotton fields were 1.6- to 2-fold greater ($P < 0.05$) than in those extending south, east, and west of the fields, and 10-fold greater than in the centers of the fields before harvest operations began (Table 1). Winds blowing from south to north were consistent during the day from 1.6 to 30 kph throughout the study, and minimum and maximum temperatures were 20 and 38°C. After harvest operations commenced, mean sums did not differ between center field traps and those peripheral to the fields regardless of the compass direction. The center trap capture during harvest operations was 18-fold greater ($P < 0.05$) than before harvest (Table 1). Otherwise, differences between trap captures before harvest and during harvest operations were not detected along each compass direction.

During the preharvest sampling interval, mean numbers of boll weevils collected in the nearest three traps to the field edge and the farthest three traps from the field edge across all four compass directions were not different, but each group of three traps collected more than the single center trap ($F = 9.73$; df = 2, 8; $P = 0.0131$). However, during harvest operations, the lowest average number of trapped boll weevils was found in the farthest three traps ($F = 8.65$; df = 2, 8; $P = 0.0171$) (Fig. 2).

Table 1. Mean ± SE numbers of boll weevils collected from large capacity boll weevil traps before and after cotton defoliation, Hidalgo County, TX, July 2004

Time[a]	Direction from field[b]	No. boll weevils collected[c]
Predefoliation	North	9.0 ± 2.6a
	South	4.6 ± 2.1b
	East	5.1 ± 1.9b
	West	4.8 ± 0.4b
	Center	0.9 ± 0.7c
Postdefoliation	North	15.0 ± 3.6a
	South	7.9 ± 3.7b
	East	7.4 ± 3.4b
	West	6.0 ± 2.5b
	Center	16.1 ± 0.9a

[a] Postdefoliation sampling included harvest and stalk-pulling operations.

[b] Large capacity boll weevil traps were placed without a pheromone lure at 15-m intervals extending away from the field in each compass direction for 180 m; center, trap was placed at the middle of each field.

[c] Means followed by different letters are significantly different ($P < 0.05$), one-way ANOVA, Tukey's HSD ($n = 3$).

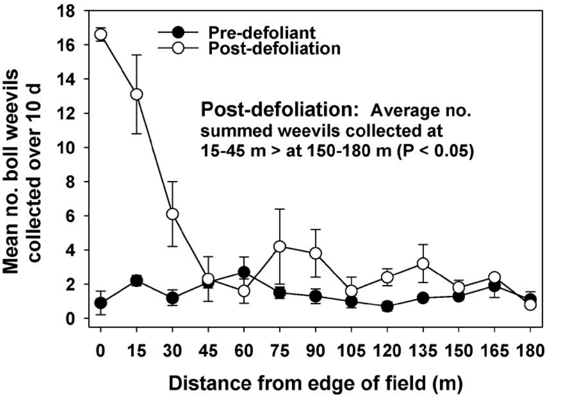

Fig. 2. Mean ± SE numbers of boll weevils captured using passive (no grandlure) large capacity traps at 15-m intervals north, south, east, and west of three different commercial cotton fields undergoing harvest operations, Hidalgo County, TX, July–August 2004 ($n = 3$).

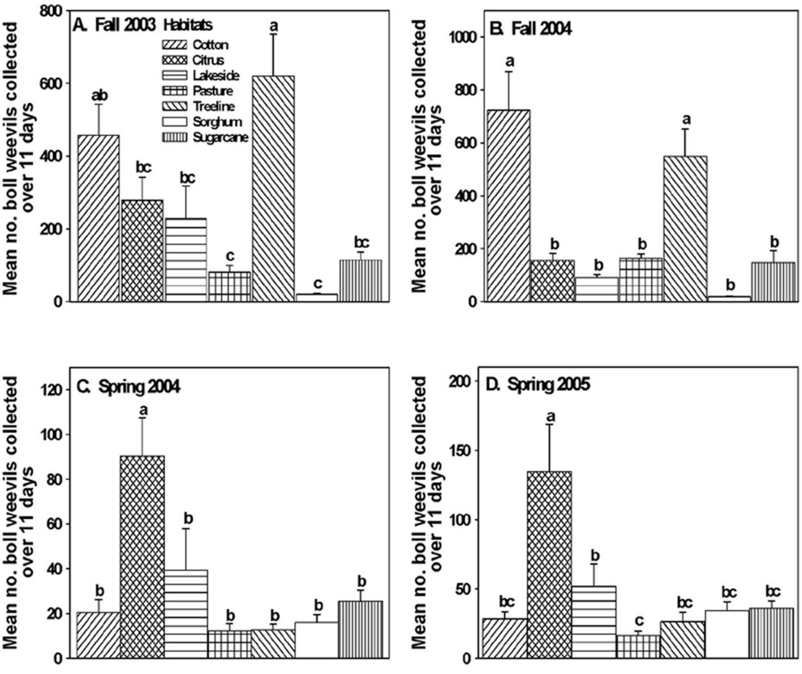

Fig. 3. Mean ± SE numbers of adult boll weevils collected in large capacity traps (each with a 10-mg grandlure strip), when cotton fields were not squaring, in seven different habitats, during 12 d in each of September (A and B) and February (C and D), 2003–2005, Hidalgo County, TX (n = 6).

Winter Habitats. Differences in mean numbers of trapped boll weevils between habitats were detected in fall 2003 (F = 7.17; df = 6, 41; $P < 0.0001$) and 2004 (F = 14.02; df = 6, 41; $P < 0.0001$). During fall 2003, the mean number of boll weevils collected in treelines adjoining harvested (fallow) cotton fields was greater ($P < 0.05$) than in any other habitat, excluding the harvested cotton fields themselves (Fig. 3A). Boll weevils in treelines were from 1.6- to 22.6-fold more abundant than in citrus orchards and fallow sorghum fields, respectively. During fall 2004, fallow cotton field and treeline boll weevils outnumbered mean populations in any of the other five habitats ($P < 0.05$) by at least 4.4- and 3.3-fold, respectively (Fig. 3B).

Habitat differences were detected in spring 2004 (F = 6.45; df = 6, 41; P = 0.0001) and 2005 (F = 7.85; df = 6, 41; $P < 0.0001$). During springs 2004 and 2005, boll weevils were ≥2.3- and ≥3.5-fold, respectively, more abundant in citrus orchards than in any of the other habitats ($P < 0.05$) (Fig. 3). Boll weevils were ≥6.8-fold more abundant along the edges of Delta Lake than Donna and La Feria lakes (F = 51.00; df = 2, 11; $P < 0.0001$) (Fig. 4).

Overwintering had different effects on boll weevil populations, depending on habitat. Mean numbers were lower in the spring than in the preceding fall in the fallow cotton (95.5–96.1%) (F = 47.70; df = 3, 23; $P < 0.0001$), pasture (85–90%) (F = 35.06; df = 3, 23; $P < 0.0001$), treeline (95.2–98%) (F = 74.28; df = 3, 23; $P < 0.0001$), sugarcane (75.5–77.7%) (F = 15.08; df = 3, 23; $P < 0.0001$), and the Donna Lake and La Feria Lake habitats (77.5–92.6%) (F = 18.89; df = 3, 15; P = 0.0001) habitats from 2003 until 2005 (Fig. 5A–E). Overwintering populations in citrus orchards were reduced during 2003–2004 only (49.7%) (F = 6.84; df = 3, 23; P = 0.0024) (Fig. 5F), and differences between fall and spring populations were not detected in the sorghum and Delta Lake habitats (Fig. 5G and H).

Mating Status and Gravidity. During the times when cotton was not being cultivated, eggs were not observed in any of the dissected females, regardless of habitat. Once squares developed in the field after mid-April, 95–100% of the female boll weevils col-

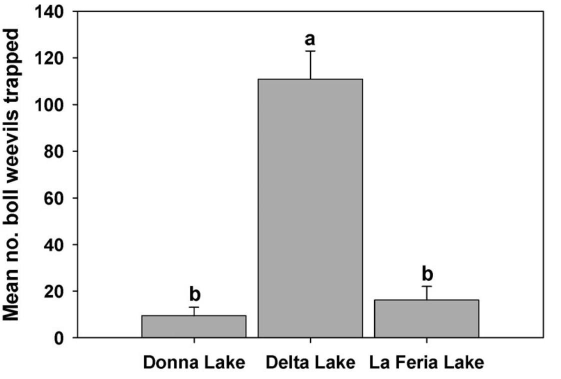

Fig. 4. Mean ± SE numbers of adult boll weevils collected in large capacity traps (each with a 10-mg grandlure strip) in vegetation at the edges of Donna, Delta, and La Feria lakes in Hidalgo County, TX, during February 2004 (n = 2).

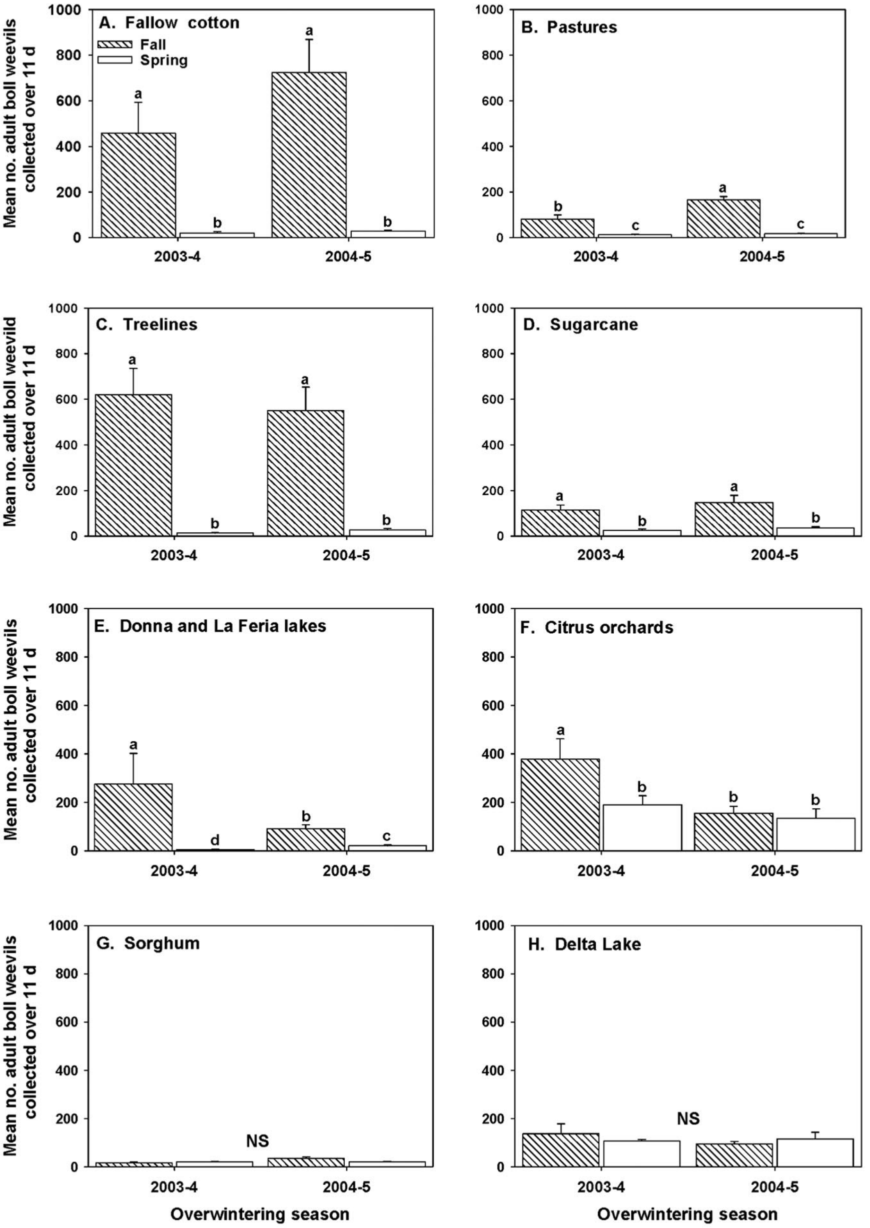

Fig. 5. Mean ± SE numbers of adult boll weevils collected in large capacity traps (each with a 10-mg grandlure strip) in eight habitats when cotton fields were not squaring during 12 d in each of September and February of 2003–2005, Hidalgo County, TX (n = 6).

lected from cotton fields contained chorionated eggs (Fig. 6A and B). Although boll weevils were collected in cotton fields throughout the year, adults were not available in sufficient numbers for dissection year-round in the treelines, at Delta Lake, and in sugarcane fields. Low numbers in those habitats occurred May–July when squares were present, but boll weevils were trapped in citrus orchards year-round. Eggs were found during August in female boll weevils collected from treelines, citrus orchards, and sugarcane fields, although repeated measures analysis showed that, over each November–August sampling period, gravid female boll weevils were more abundant in cotton fields than in any other habitat from May to August (F = 14.37; df = 4, 855; P < 0.0001) (Fig. 6A and B).

Although numbers of females with discolored spermatheca were not affected by habitat, populations pooled among habitat types had ≥25% fewer females

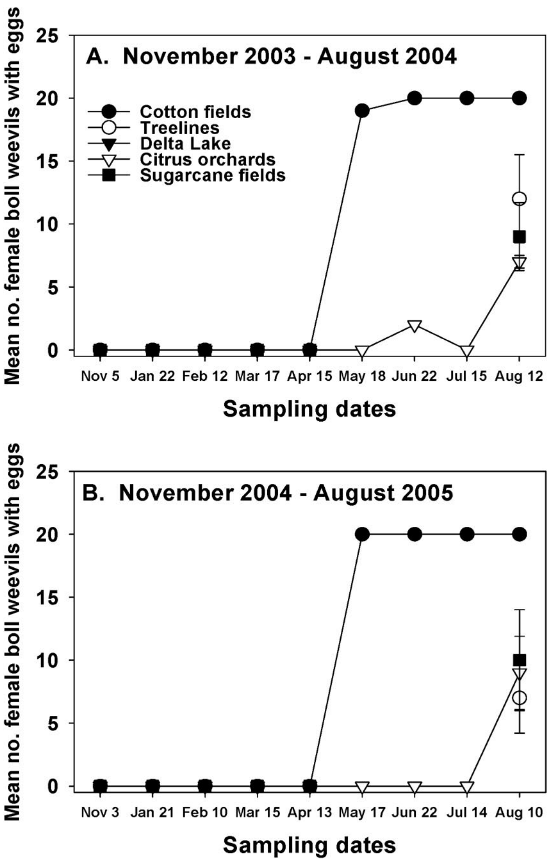

Fig. 6. Mean ± SE numbers of gravid female boll weevils collected 2003–2005 in five habitats (n = 20 weevils, no data point indicates that no weevils were collected at that time), Hidalgo County, TX.

with discolored spermatheca (F = 16.41; df = 5, 839; $P < 0.0001$) in February than in the other four months when sampling occurred before cotton plants began to square in late April 2005 (Fig. 7).

Discussion

Boll weevil adults are known to fly in large numbers when their chief habitat, fruiting cotton fields, is undergoing routine harvest-related operations (Cowan et al. 1963, Showler 2003). Without using pheromone-baited traps that can attract them from undetermined distances, our study indicates that boll weevils do not move quickly (e.g., within days) after harvest operations in large numbers much beyond 30 m from cotton field edges. Elimination of the cotton crop causes boll weevils to search for secondary (noncotton) food sources (Guerra 1986, Jones and Coppedge 1999), but substantial numbers of boll weevils remain in the field even after cotton is defoliated, harvested, and shredded (Cowan et al. 1963, Showler 2003), presumably because of the cotton plant material, including bolls, left on or under the soil surface (Cowan et al. 1963, Rummel and Summy 1997, Greenberg et al. 2004).

Of the weevils that were passively trapped outside the cotton fields, most were at the north edge of the field, which agrees with the findings of Guerra (1983) and suggests that the prevailing south-to-north wind influenced this trend. Guerra and Garcia (1982) reported that ≈90% of trap-captured boll weevils in the subtropical Lower Rio Grande Valley were collected when cotton was being harvested and during the fall (July–November), 70% of all captured boll weevils were collected in treelines adjacent to cotton fields, and when a treeline was destroyed, boll weevil populations declined there to levels typically encountered along other, nonwooded, field edges. Our study shows that trap captures during September were greatest in harvested cotton fields and adjacent treelines. It is likely that boll weevils were collected in great numbers in treelines after harvest in the fall because of the proximity of treelines to cotton fields, and boll weevils consume pollen from some plant species common to the Lower Rio Grande Valley (Benedict et al. 1991, Jones and Coppedge 1999). This work shows that boll weevils do not emigrate from defoliated, harvested, or tilled cotton fields in a single "pulse"; instead, the weevils move more gradually over a period of weeks to treelines.

By spring, however, trap captures were greatest in citrus orchards despite some attrition that occurred during the winter. It seems that boll weevils were either able to survive better in citrus orchards than in other habitats during the winter, or, if survival of individual boll weevils was not enabled in the citrus habitat, then adult boll weevils might have continued to arrive from other habitats throughout the winter. Although traps deployed on lake edges collectively captured fewer boll weevils than citrus orchards, traps at Delta Lake had 22% more weevils than traps in orchards in spring 2004 but 29% fewer in spring 2005. Declines in overwintering boll weevil populations to relatively low levels in fallow cotton fields, pastures, treelines, sugarcane, and Donna and La Feria lakes indicate that those habitats do not sustain boll weevils in substantial numbers or serve as major sources of adult boll weevils that infest cotton during the spring.

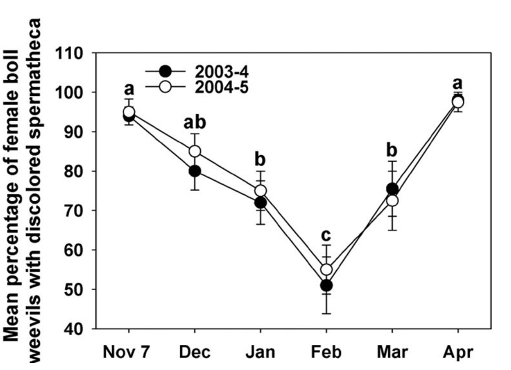

Fig. 7. Mean ± SE percentages of female boll weevils that had mated (as indicated by discolored spermatheca) November–April 2003–2005, Hidalgo County, TX (n = 20 weevils).

Delta Lake, with citrus as the most important alternative habitat, maintained relatively high numbers of boll weevils through both winters. We therefore suggest that citrus orchards and habitats such as those found on the edge of Delta Lake are examples of overwintering "hot spots" for boll weevils in the subtropical Lower Rio Grande Valley of Texas. Other hot spots likely exist in the Lower Rio Grande Valley and in other subtropical and tropical cotton-growing areas in the boll weevil's distribution. Conversely, the sorghum habitat harbored the fewest boll weevils in both the fall and spring.

We have maintained newly emerged overwintering adult boll weevils alive in petri dishes on prickly pear (*Opuntia* sp.) fruit, common to Mesoamerican tropics and subtropics, for >3 mo (A.T.S., unpublished data), whereas overwintering boll weevils fed on cotton seedlings, terminals, or squares survived averages of 8.1, 45, and 80 d, respectively (Fenton and Dunnam 1929, Hunter and Hinds 1905).

With some exceptions, most alternate food hosts of the boll weevil are not associated with egg development (Cross et al. 1975, Bariola 1984, Benedict et al. 1991). The greater concentrations of boll weevils in citrus orchards and at Delta Lake result from immigration, greater survivorship than in other habitats, or both. That the weevils are found in substantial numbers at all in citrus orchards suggests some level of attraction, and it is known that adult boll weevils can be sustained on sugary substances (Haynes 1985), but our study showed that reproduction was not occurring in those habitats. However, we have come across fields of volunteer squaring cotton in February, during the mandatory cotton-free period in the Lower Rio Grande Valley (Texas Department of Agriculture 2002), that were 100% infested with boll weevils indicating that wintertime reproduction occurs (Guerra et al. 1982, Summy et al. 1988).

Greenberg et al. (2001) and Sappington et al. (2001, 2002) reported negligible boll weevil movement or dispersal from an experimental field associated with application of insecticides and chemical defoliants, but their experiments involved narrow treatment plots (≤6 rows) and grandlure-baited Hercon traps positioned around the edges of the field, all of which might affect the results of the mark–recapture method. In addition, the external marker used might have altered boll weevil behavior (Southwood 1966, Showler et al. 1988). Other experiments on short-range dispersal during and after harvest operations have indicated that weevils move from cotton fields into the edges of wooded areas or treelines peripheral to the field, but substantial populations stay in the fallow field (Fye et al. 1959, Cowan et al. 1963, Guerra and Garcia 1982, Wolfenbarger et al. 1982, Showler 2003). Hardee et al. (1969) reported that boll weevils generally overwinter near cotton fields.

Curculionids are not known to migrate between specific locations like monarch butterflies, *Danaus plexippus* L. (Gibo and McCurdy 1993), or as groups, or swarms, on prevailing winds as with desert locusts, *Schistocerca gregaria* Forskål (Steedman 1988; Showler 1993, 1995). It seems more likely that long-range movement of boll weevils is passive and accidental, largely reliant on wind currents. As an example of how insects can be carried substantial distances on prevailing winds, at least one swarm of desert locusts, comprised of millions of individuals, was carried by a weather front from Mauritania across the Atlantic Ocean to islands in the Caribbean and Venezuela (Showler and Potter 1991). Guerra (1988) reported that boll weevils fed on bolls tended to fly upward when released. If some boll weevils do fly upward, whether instigated by food source or not, there is a chance that the weevils would encounter wind currents that might direct them elsewhere. Rather than being a dispersal mechanism that actually targets squaring cotton elsewhere to ensure survival and reproduction, boll weevils on wind currents might be spread to favorable and unfavorable habitats alike, much like plant seeds that rely on wind for dispersal (Nathan et al. 2002). This can explain how boll weevils have been trapped far from host plants (Jones et al. 1992), or from the site of boll weevil releases (Johnson et al. 1975, Guerra 1988).

This study shows that female boll weevils do not produce eggs in any of the habitats that were examined during the overwinter period. Once cotton fruiting bodies become available in the spring-planted fields, egg production became evident. Although some females collected during the late part of the cotton-growing season carried eggs in other habitats, this was not a result of feeding on the plants (none of them were cotton plants) in those habitats. Instead, gravid females likely moved from fruiting cotton fields to nearby habitats after harvest operations and these females were collected in the pheromone-baited traps. Although the noncotton habitats can play an important role in the survival of adult boll weevils during the overwinter period, reproduction does not occur unless cotton fruiting bodies, and a few other hosts suitable for reproduction but not present in the habitats we studied, are available for egg production and oviposition (Cross et al. 1975, Jones et al. 1992, Hardee et al. 1999, Showler 2004). The observed reduction in mating, as determined by discoloration of spermatheca, indicates a reduction in reproductive activity during the interval January–March when host plants conducive to reproduction are sparse or absent. The observed decline in mating activity might be the result of lower winter temperatures that generally commence in December in the Lower Rio Grande Valley and persist through February until sometime in March.

The populations of adult boll weevils collected in citrus orchards and at Delta Lake represent substantial sources of overwintered populations that can enter squaring cotton fields during the spring. Identifying concentrations of overwintered boll weevils in specific habitats during the spring can provide opportunities for new tactics that augment boll weevil eradication (Dickerson et al. 2001) or suppression efforts. Because overwintered boll weevils move from overwintering habitats to fruiting cotton fields over several months rather than at the same time (Rummel and Summy 1997), application of the short-residual pesticides (<4 d) currently available (Showler and Scott 2005) needs to be applied repetitively. In areas where pesticide applications cannot or should not occur for environmental or safety reasons, deployment of nontoxic methods, such as large capacity boll weevil traps that are more efficient at capturing and killing adult boll weevils than the Hercon trap (Showler 2003) should be considered as a technique for reducing the substantial overwintered populations encountered in hot spots.

Acknowledgment

We thank Jaime Cavazos and Veronica Abrigo for technical assistance, and Don Thomas, Greg Sword, and Mamoudou Sétamou for critical reviews.

References Cited

Analytical Software. 1998. Statistix for Windows. Analytical Software, Tallahassee, FL.

Bariola, L. A. 1984. Longevity and reproduction of overwintering boll weevils on cotton and alternate hosts. Southwest. Entomol. 9: 253–255.

Beckham, C. M. 1957. Hibernation sits of the boll weevil in relation to a small, Georgia piedmont cotton field. J. Econ. Entomol. 50: 833–834.

Beerwinkle, K. R., J. D. Lopez, Jr., and G. H. McKibben. 1996. Seasonal responses of boll weevils to pheromone traps in cropped and adjacent uncropped areas of east-central Texas. Southwest Entomol. 21: 407–419.

Benedict, J. H., D. A. Wolfenbarger, V. M. Bryant, Jr., and D. M. George. 1991. Pollens ingested by boll weevils (Coleoptera: Curculionidae) in southern Texas and Northeastern Mexico. J. Econ. Entomol. 84: 126–131.

Bondy, F. P., and C. F. Rainwater. 1942. Boll weevils hibernation, survival, and emergence under South Carolina conditions. J. Econ. Entomol. 35: 495–498.

Bottrell, D. G., J. R. White, D. S. Moody, and D. D. Hardee. 1972. Overwintering habitats of the boll weevil in the Rolling Plains of Texas. Environ. Entomol. 1: 633–638.

Brazzel, J. R., and L. D. Newsom. 1959. Diapause in *Anthonomus grandis* Boh. J. Econ. Entomol. 52: 603–611.

Brown, C. M., and S. A. Phillips, Jr. 1989. Weeping lovegrass as an overwintering habitat for the boll weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 82: 799–802.

Burke, H. R., W. E. Clark, J. R. Cate, and P. A. Fryxell. 1986. Origin and dispersal of the boll weevil. Bull Entomol. Soc. Am. 32: 228–238.

Carroll, S. C., D. R. Rummel, and E. Segarra. 1993. Overwintering by the boll weevil (Coleoptera: Curculionidae) in conservation reserve program grasses on the Texas High Plains. J. Econ. Entomol. 86: 382–393.

Cowan, C. B., Jr., J. W. Davis, and C. R. Parencia, Jr. 1963. Winter survival of the boll weevil in cotton bolls in central Texas. J. Econ. Entomol. 56: 494–496.

Cross, W. H., M. J. Lukefahr, P. A. Fryxell, and H. R. Burke. 1975. Host plants of the boll weevil. Environ. Entomol. 4: 19–26.

Dickerson, W. A., A. L. Brashear, J. T. Brumley, F. L. Carter, W. J. Grefenstette, and F. A. Harris [eds.]. 2001. Boll weevil eradication in the United States through 1999. The Cotton Foundation, Memphis, TN.

Fenton, F. A., and E. W. Dunnam. 1929. Biology of the cotton boll weevil at Florence, S.C. U.S. Dep. Agric. Tech. Bull No. 112.

Fye, R. E., W. W. McMillian, R. L. Walker, and A. R. Hopkins. 1959. The distance into woods along a cotton field at which the boll weevil hibernates. J. Econ. Entomol. 52: 310–312.

Gibo, D. L., and J. A. McCurdy. 1993. Lipid accumulation by migrating monarch butterflies (*Danaus plexippus* L.). Can. J. Bot. 71: 76–82.

Greenberg, S. M., T. W. Sappington, J. Norman, and A. Sparks, Jr. 2001. Effects of defoliants alone or in combination with insecticides on boll weevil and whitefly in cotton: C. Boll weevil field tests, pp. 977–980. *In* Proceedings of the Beltwide Cotton Conference, National Cotton Council, Memphis, TN.

Greenberg, S. M., A. T. Showler, T. W. Sappington, and J. M. Bradford. 2004. Effects of burial and soil condition on post harvest mortality of boll weevils (Coleoptera: Curculionidae) in fallen cotton fruit. J. Econ. Entomol. 97: 409–413.

Guerra, A. A., and R. D. Garcia. 1982. Seasonal patterns of boll weevil response to grandlure-baited traps in the subtropical Rio Grande Valley of Texas. Southwest. Entomol. 7: 216–220.

Guerra, A. A., R. D. Garcia, and J. A. Tamayo. 1982. Physiological activity of the boll weevil during the fall and winter in subtropical areas of the Rio Grande Valley of Texas. J. Econ. Entomol. 75: 11–15.

Guerra, A. A. 1983. Daily attractive response patterns of boll weevils to grandlure traps in the Lower Rio Grande Valley of Texas. Southwest Entomol. 8: 252–258.

Guerra, A. A., R. F. Garcia, P. R. Bodegas, and M. E. De Coss. 1984. The quiescent physiological status of boll weevils (Coleoptera: Curculionidae) during the noncotton season in the tropical zone of Soconusco in Chiapas, Mexico. J. Econ. Entomol. 77: 595–598.

Guerra, A. A. 1986. Boll weevil movement: dispersal during and after the cotton season in the Lower Rio Grande Valley of Texas. Southwest. Entomol. 11: 10–16.

Guerra, A. A. 1988. Seasonal boll weevil movement between northeastern Mexico and the Rio Grande Valley of Texas, USA. Southwest Entomol. 13: 261–171.

Hardee, D. D., W. H. Cross, and E. B. Mitchell. 1969. Male boll weevils are more attractive than cotton plants to boll weevils. J. Econ. Entomol. 62: 165–169.

Hardee, D. D., G. D. Jones, and L. C. Adams. 1999. Emergence, movement, and host plants of boll weevils (Coleoptera: Curculionidae) in the Delta of Mississippi. J. Econ. Entomol. 92: 130–139.

Haynes, J. 1985. Sterile boll weevils (Coleoptera: Curculionidae) fed 10% sugar diets: effect on longevity, mating, and flight. J. Econ. Entomol. 78: 783–786.

Hunter, W. D., and W. E. Hinds. 1905. The Mexican boll weevil. U.S. Dep. Agric. Bur. Entomol. Bull. No. 51.

Johnson, W. L., W. H. Cross, J. E. Leggett, W. L. McGovern, H. C. Mitchell, and E. B. Mitchell. 1975. Dispersal of marked boll weevil: 1970–1973 studies. Ann. Entomol. Soc. Am. 68: 1018–1022.

Jones, G. D., and J. R. Coppedge. 1999. Foraging resources of boll weevils (Coleoptera: Curculionidae). J. Econ. Entomol. 92: 860–869.

Jones, R. W., J. R. Cate, E. M. Herndandez, and R. T. Navarro. 1992. Hosts and seasonal activity of the boll weevil (Coleoptera: Curculionidae) in tropical and subtropical habitats of northeastern Mexico. J. Econ. Entomol. 85: 74–82.

Knutson, A. E., and W. T. Wilson. 1999. The beat bucket: a rapid, reliable method for sampling predatory insects and spiders in cotton, pp. 1120–1125. *In* Proceedings of the Beltwide Cotton Conference, National Cotton Council, Memphis, TN.

Knutson, A. E., S. E. Naranjo, L. T. Wilson, and M. A. Muegge. 2000. Sampling insects and spiders with the beat bucket method in Texas and Arizona, pp. 1257–1259. *In* Proceedings of the Beltwide Cotton Conference, National Cotton Council, Memphis, TN.

Nathan, R., G. G. Katul, H. S. Horn, S. M. Thomas, R. Oren, R. Avissar, W. W. Pacala, and S. A. Levin. 2002. Mechanisms of long-distance dispersal of seeds by wind. Nature (Lond.) 418: 409–413.

Parajulee, M. N., and J. E. Slosser. 2001. Effect of ethephon on efficacy of grandlure-baited pheromone traps in surveying fall and spring populations of the boll weevil (Coleoptera: Curculionidae). Environ. Entomol. 30: 64–69.

Pieters, E. P., and T. C. Urban. 1977. Dispersal of the boll weevil in the Coastal Bend area of Texas. Southwest. Entomol. 2: 4–7.

Rummel, D. R., and K. R. Summy. 1997. Ecology of the boll weevil in the United States Cotton Belt. Southwest. Entomol. 22: 356–376.

Sappington, T. W., S. M. Greenberg, A. Sparks, Jr., and J. Norman. 2001. Effects of defoliants alone or in combination with insecticides on boll weevil and whitefly in cotton: E. Boll weevil dispersal behavior, pp. 984–987. *In* Proceedings of the Beltwide Cotton Conference, National Cotton Council, Memphis, TN.

Sappington, T. W., S. M. Greenberg, A. N. Sparks, Jr., and G. W. Elzen. 2002. Dispersal of boll weevils after exposure to defoliants and insecticides, CD-ROM. *In* Proceedings of the Beltwide Cotton Conference, National Cotton Council, Memphis, TN.

Showler, A. T. 1993. Desert locust, *Schistocerca gregaria* (Forskal) (Orthoptera: Acrididae), campaign in Tunisia, 1988. Agric. Syst. 42: 311–325.

Showler, A. T. 1995. Locust (Orthoptera: Acrididae) outbreak in Africa and Asia, 1992–1994: an overview. Am. Entomol. 41: 179–185.

Showler, A. T. 2003. Effects of routine late-season field operations on numbers of boll weevils (Coleoptera: Curculionidae) captured in large-capacity pheromone traps. J. Econ. Entomol. 96: 680–689.

Showler, A. T. 2004. Influence of adult boll weevil (Coleoptera: Curculionidae) food resources on fecundity and oviposition. J. Econ. Entomol. 97: 1330–1334.

Showler, A. T. 2005. Relationships of different cotton square sizes to boll weevils (Coleoptera: Curculionidae) in field conditions. J. Econ. Entomol. 98: 1572–1579.

Showler, A. T., and C. S. Potter. 1991. Synopsis of the 1986–1989 desert locust (Orthoptera: Acrididae) plague and the concept of strategic control. Am. Entomol. 37: 106–110.

Showler, A. T., and A. W. Scott, Jr. 2005. Effects of insecticide residues on adult boll weevils and immatures developing inside fallen cotton fruit. Subtrop. Plant Sci. 56: 33–38.

Showler, A. T., and J.R.C. Robinson. 2005. Proactive spraying against boll weevils (Coleoptera: Curculionidae) reduces insecticide applications and increases cotton yield and economic return. Econ. Entomol. 98: 1977–1983.

Showler, A. T., R. M. Knaus, and T. E. Reagan. 1988. The versatility of radiotracer methods for studying insect ethology and ecology. Fla. Entomol. 71: 554–580.

Showler, A. T., S. M. Greenberg, A. W. Scott, Jr., and J.R.C. Robinson. 2005. Effects of planting dates on boll weevils (Coleoptera: Curculionidae) and cotton fruit in the subtropics. J. Econ. Entomol. 98: 796–804.

Southwood, T.R.E. 1966. Ecological methods with particular reference to the study of insect populations. Methuen & Co., London, United Kingdom.

Steedman, A. 1988. The locust handbook. Overseas Development Natural Resources Institute, London, United Kingdom.

Summy, K. R., J. R. Cate, and W. G. Hart. 1988. Overwintering strategies of boll weevil in southern Texas: reproduction on cultivated cotton. Southwest. Entomol. 13: 159–165.

Texas Department of Agriculture. 2002. Administrative Code, Title 4, Part 1, Chapter 20, Subchapter A, Rule 20.1, Texas Department of Agriculture, Austin, TX.

Tumlinson, J. H., D. D. Hardee, R. C. Gueldner, A. C. Thompson, P. A. Heden, and J. P. Minyard. 1969. Sex pheromones produced by male boll weevils: isolation, identification and synthesis. Science (Wash., DC) 166: 1010–1012.

Wade, L. J., and D. R. Rummel. 1978. Boll weevil immigration into habitat and subsequent spring and summer emergence. J. Econ. Entomol. 71: 173–178.

Wolfenbarger, D. A., H. M. Graham, J. B. Nosky, and O. H. Lindig. 1982. Boll weevil (Coleoptera: Curculionidae): marking with rubidium chloride sprays on cotton and dispersal from cotton. J. Econ. Entomol. 75: 1038–1041.

Received 24 January 2006; accepted 24 January 2006.